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OPERATION BREN

GENERAL CORRELATIVE STUDIES—OPERATION BREN

J. A. Auxier, F. F. Haywood, and L. W. Gilley

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GENERAL CORRELATIVE STUDIES—OPERATION BREN

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ABSTRACT

A summary of the utilization of the Health Physics Research Reactor and a Co^{60} source during Operation BREN has been prepared, and the pertinent meteorological data have been tabulated. Normalization factors for air dose, as it depends on air density and reactor power level, are obtained as a function of source height; typical dose vs. distance curves are presented. For a source height of 1125 ft and with the detector at the surface of the ground, the relaxation length in air is 230 yards for neutrons from the reactor, 311 yards for gamma radiation from the reactor (including gamma rays from inelastic interactions by neutrons in air), and 256 yards for the gamma rays from Co^{60}. These reduce to 181, 245, and 200 yards, respectively, at 760 mm Hg pressure and 0°C. This is the third of a series of Operation BREN reports and the first concerning experimental results.

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CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS (Continued)

TABLES

Chapter 1

INTRODUCTION

The experiments for which Operation BREN[1,2] (Bare Reactor Experiment, Nevada) was undertaken were a continuation of the Ichiban Program begun in 1956 for evaluating the radiation exposures received by persons exposed to the nuclear detonations at Hiroshima and Nagasaki, Japan. This program is directed by the Health Physics Division of the Oak Ridge National Laboratory (ORNL) in cooperation with the Atomic Bomb Casualty Commission. Earlier experiments were conducted during weapons-test Operations Teapot (pre-Ichiban), Plumbbob,[3,4] and Hardtack, Phase II.[5]

In addition to the Ichiban studies (Program 1), four other programs were included in the studies: Program 3, from the Neutron Physics Division, ORNL; Program 4, from the Health Physics Division, University of California Lawrence Radiation Laboratory, Berkeley, Calif.; Program 5, from the United States Naval Radiological Defense Laboratory, San Francisco, Calif.; and Program 7, from the Armed Forces Radiobiology Research Institute, Bethesda, Md. Program 2, also from the Health Physics Division of ORNL, utilized different sources positioned on the ground and will be reported separately. Program 6 was canceled.

This report outlines the operation of the reactor and the Co^{60} source, gives the pertinent meteorological and normalization data, and presents a preliminary analysis of the dose* vs. distance curves. It is intended also to present information of use to all programs and thus minimize the descriptive literature necessary in reports of each program or project. A more detailed report describing the background of this program, together with analyses of the data and comparisons with theory, will be presented in an open-literature publication at a later date.

For Operation BREN the ORNL Health Physics Research Reactor (HPRR), shown in Fig. 1.1, was suspended at several elevations up to 1500 ft above the ground on a 1527-ft-high tower (Fig. 1.2) located at the Nevada Test Site (NTS).

Such a reactor provides a good simulation of the neutron field resulting from the detonation of a nuclear weapon. In both cases, i.e., reactor and weapon, the leakage neutrons escape from the assembled fissile material and are moderated by air. At distances from the source greater than a few hundred yards, equilibrium obtains in the neutron spectrum, and energy and angular distributions are not sensitive functions of the design of the neutron source.[4] Use of a reactor operating in the steady-power-level mode permits use of sensitive "in-laboratory" type instruments that could not be used for brief intervals at high dose rates or with blast conditions present.

Several components of the gamma-ray field of a nuclear device are well simulated by means of a bare reactor. Because the neutron field so closely approximates that from a weapon, the gamma rays originating in neutron–air interactions will have approximately the same energy and angular distributions as the corresponding gamma rays from nuclear weapons.

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*In this report the term "dose" or "air dose" is used to designate tissue dose in rads as measured with "first-collision" dosimeters.

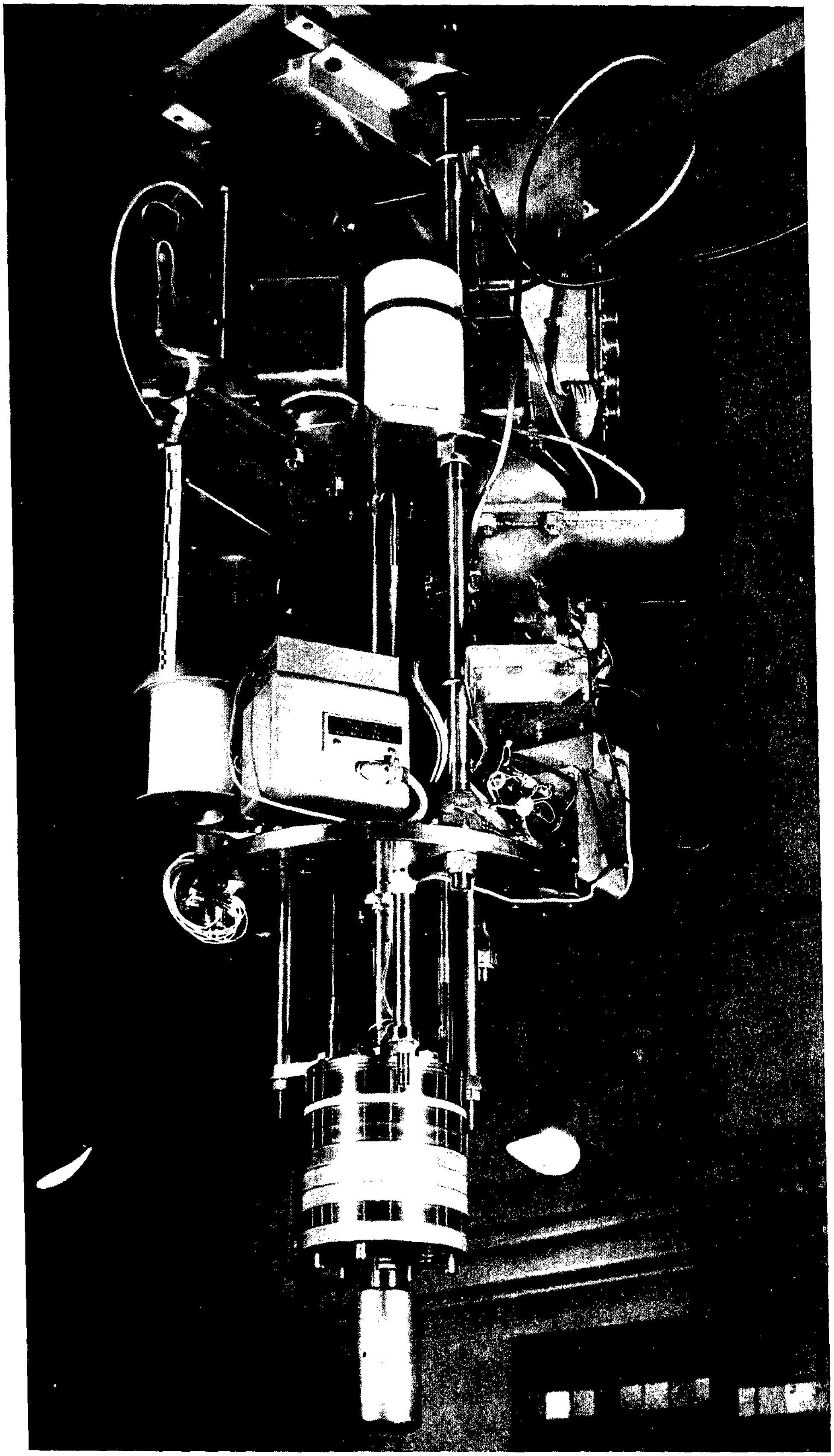

Fig. 1.1—ORNL Health Physics Research Reactor.

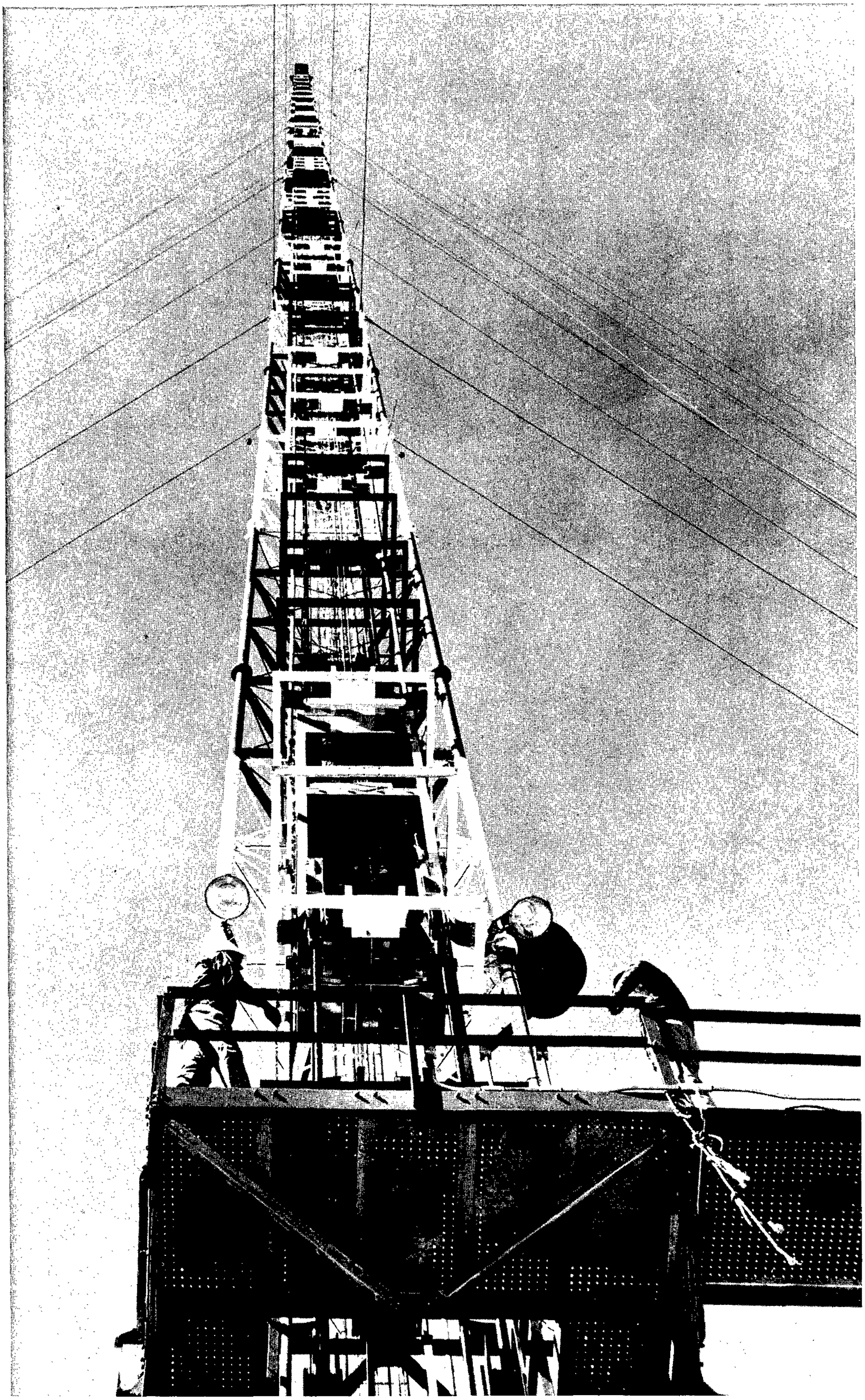

Fig. 1.2—BREN tower with HPRR mounted in hoist car at a height of 27 ft.

Prompt gamma rays from fission leak through the assembled fissile material as do those from fission in weapons. The gamma rays from fission products in a reactor, however, leak from the assembled fissile material, whereas fission products from a weapon detonation are distributed in an expanding and rising cloud. To extend the gamma-ray studies, a 1200-curie Co^{60} point gamma-ray source was substituted for the HPRR after the reactor studies were completed.

A detailed description of the radiation sources, the hazards analysis, and the operating procedures are given in Ref. 2. A general description of the BREN area is included here, however, for clarity.

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4. R. H. Ritchie and G. S. Hurst, Penetration of Weapons Radiation: Application to the Hiroshima–Nagasaki Studies, *Health Phys., 1:* 390-404 (1959).
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Chapter 2

GENERAL BREN AREA

The BREN tower, shown in Fig. 1.2, is triangular in cross section, with three legs on 10-ft centers. It is well braced by 36 guy wires. It is oriented with one side facing east directly along the main access road. The shaft, or raceway, in which the hoist car traveled is on this east face; this permitted use of the most convenient areas with a minimum of perturbation of the radiation field.

Figure 2.1 shows the position and orientation of the major facilities and work areas.

2.1 HOIST-CAR AND ELECTRICAL-CABLE CONFIGURATIONS

The HPRR (and, later, the Co^{60} source) was suspended in an aluminum hoist car (Fig. 2.2). The hoist car moved on two rails inside a framework shaft (Fig. 2.3). With the car in its lowest position, the reactor core was 27 ft above grade; the highest point at which the sources were positioned was 1500 ft above grade. An underground bunker (Building 4-300) was used as a reactor and source control room. Located approximately 100 ft from the tower base, the bunker provided 4 ft of concrete and approximately 10 ft of earth cover for shielding; it had a maze entrance with three turns of 90° each. Reactor and source control cables (two) were continuous from the reactor console to a terminal box at the 760-ft elevation on the tower. Two other cables were continuous from the terminal box to the hoist car. These latter cables passed under a set of flying wheels, which were semi-independently suspended between the guide rails for the hoist car. These wheels kept a relatively uniform stress on the cables and helped prevent excessive movement of the cables due to wind. In addition, flaps of belting material were placed at 20-ft intervals along the shaft (see Fig. 2.3) to prevent excessive lateral cable motion. However, both means failed with wind velocities greater than 20 mph, and the cables had to be held in place by heavy cords tied around structural members when such winds occurred.

2.2 SYSTEMS FOR RADIATION-YIELD NORMALIZATION

Operational procedures and equipment provided several methods of data normalization or standardization. The reactor control instrumentation included an ionization-chamber channel with strip-chart recorder. A primary count-rate channel with strip chart and "differential" and integral count readout was provided at the 790- and/or 1000-yard stations. Beginning with run No. 21, a sulfur pellet was positioned at a fixed point on the reactor hoist car (28.5 in. from the center of the core) for each run. The $S^{32}(n,p)P^{32}$ reaction was then used as the basis for an integral normalizing reference. The analysis technique was that given in Ref. 1.

The primary normalization channel comprised a BF_3 proportional counter, mounted axially in a cylindrical paraffin shield, and associated electronic equipment. The surface of the BF_3 counter (except for the ends) was covered with 9.4 cm of paraffin, which was sufficient to render the counter relatively insensitive to small changes in neutron spectrum. Figure 2.4

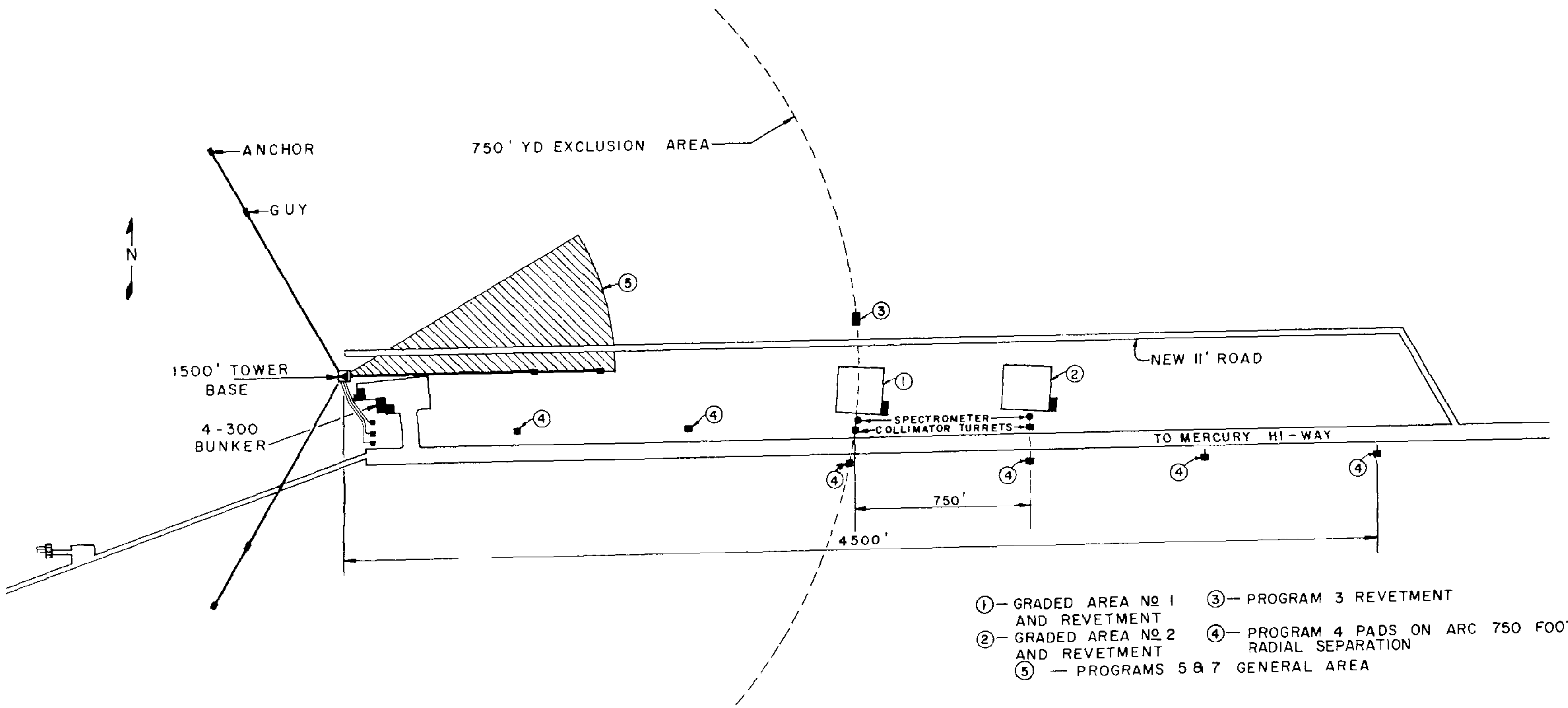

Fig. 2.1—Map of BREN vicinity in Area 4 of Nevada Test Site.

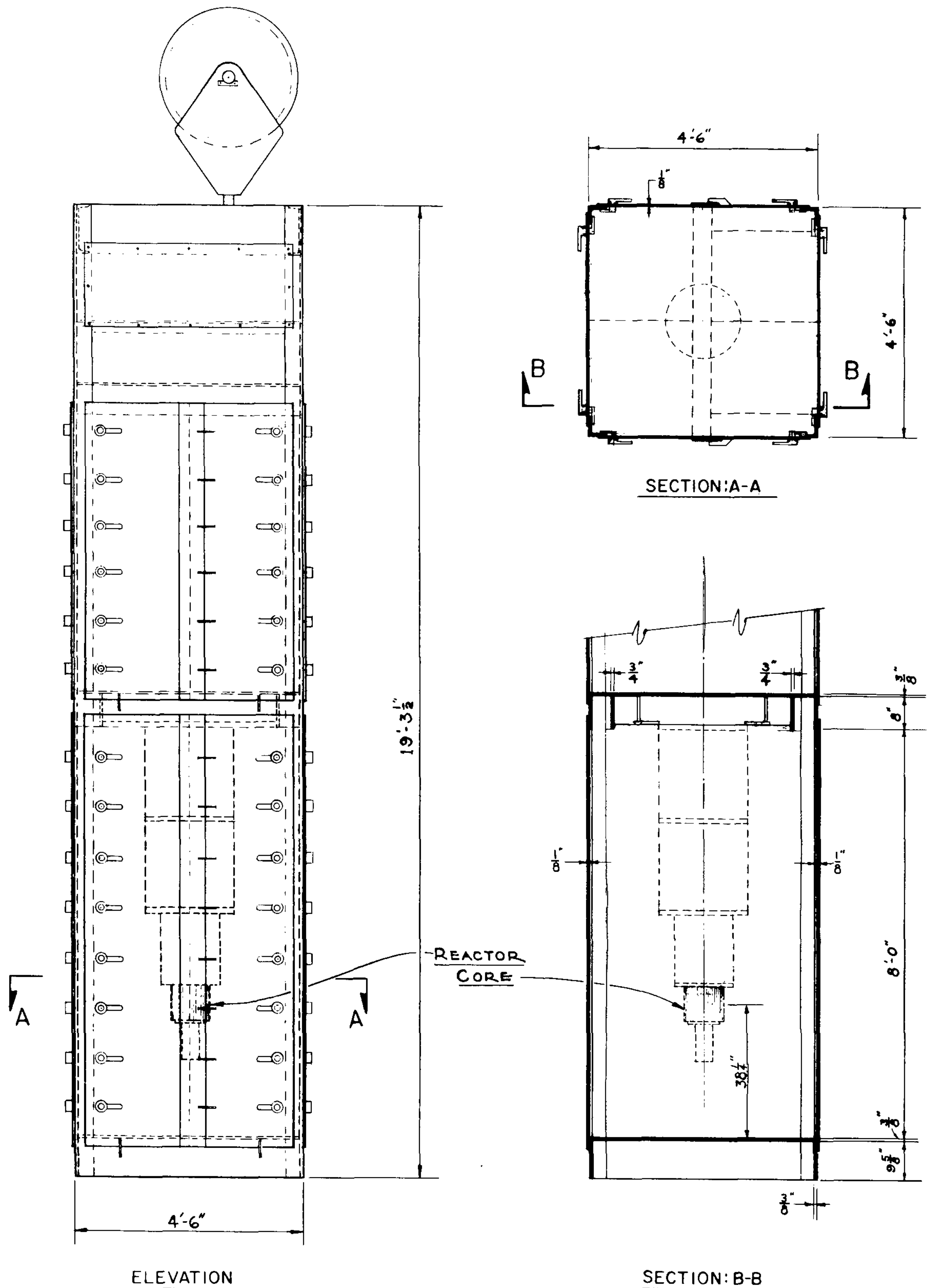

Fig. 2.2—Sketch of aluminum hoist car.

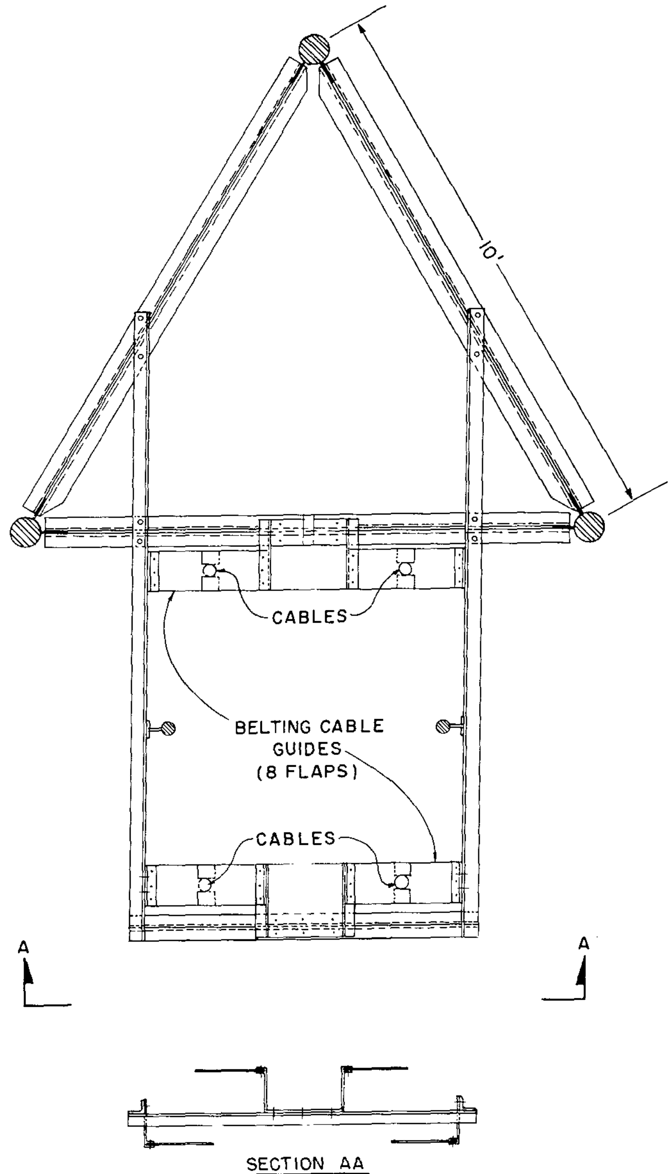

Fig. 2.3a — Plan view of tower and elevator shaft.

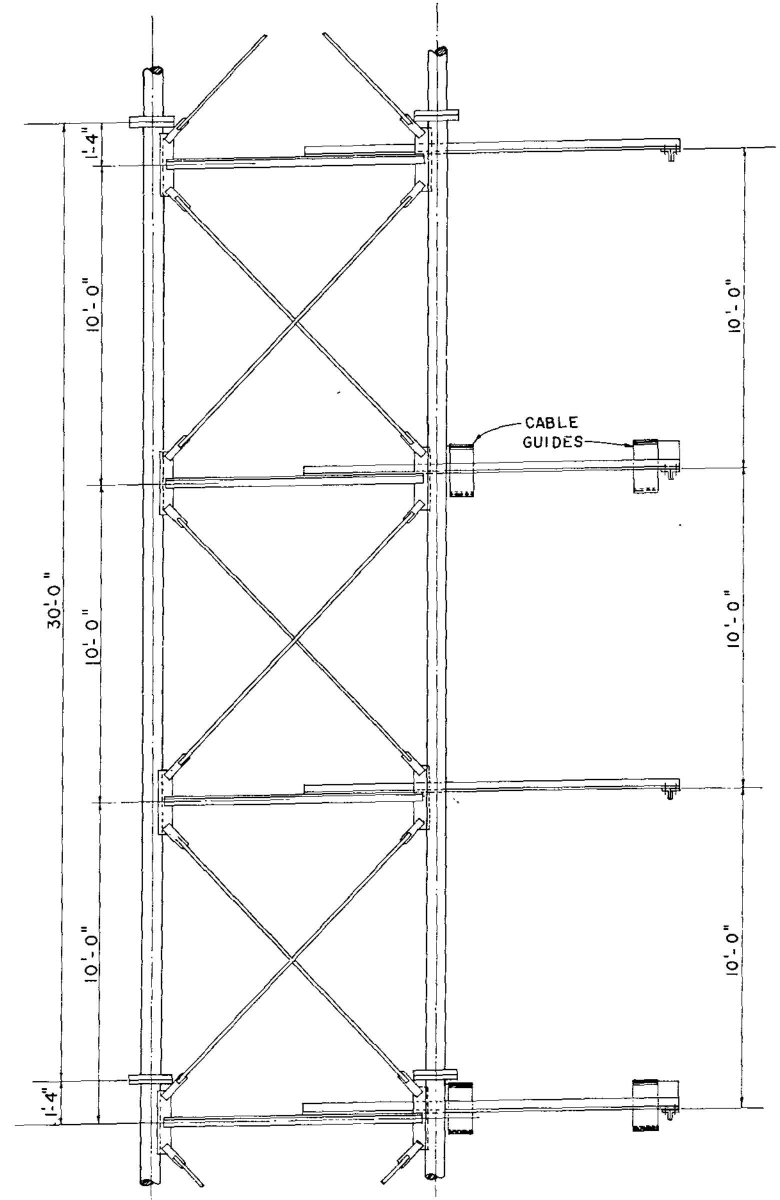

Fig. 2.3b — Sectional view of tower and elevator shaft.

shows the detector and mounting arrangement. Figure 2.5 shows the response of this normalizing channel as neutron energy, relative to the response of the Hanson-McKibben long counter. Similarly, a secondary normalization channel was utilized. Here the moderator was wood and was approximately 34 cm thick and 61 cm long. In each case the axis of the cylinder was oriented normal to the vertical plane containing the detector and the reactor.

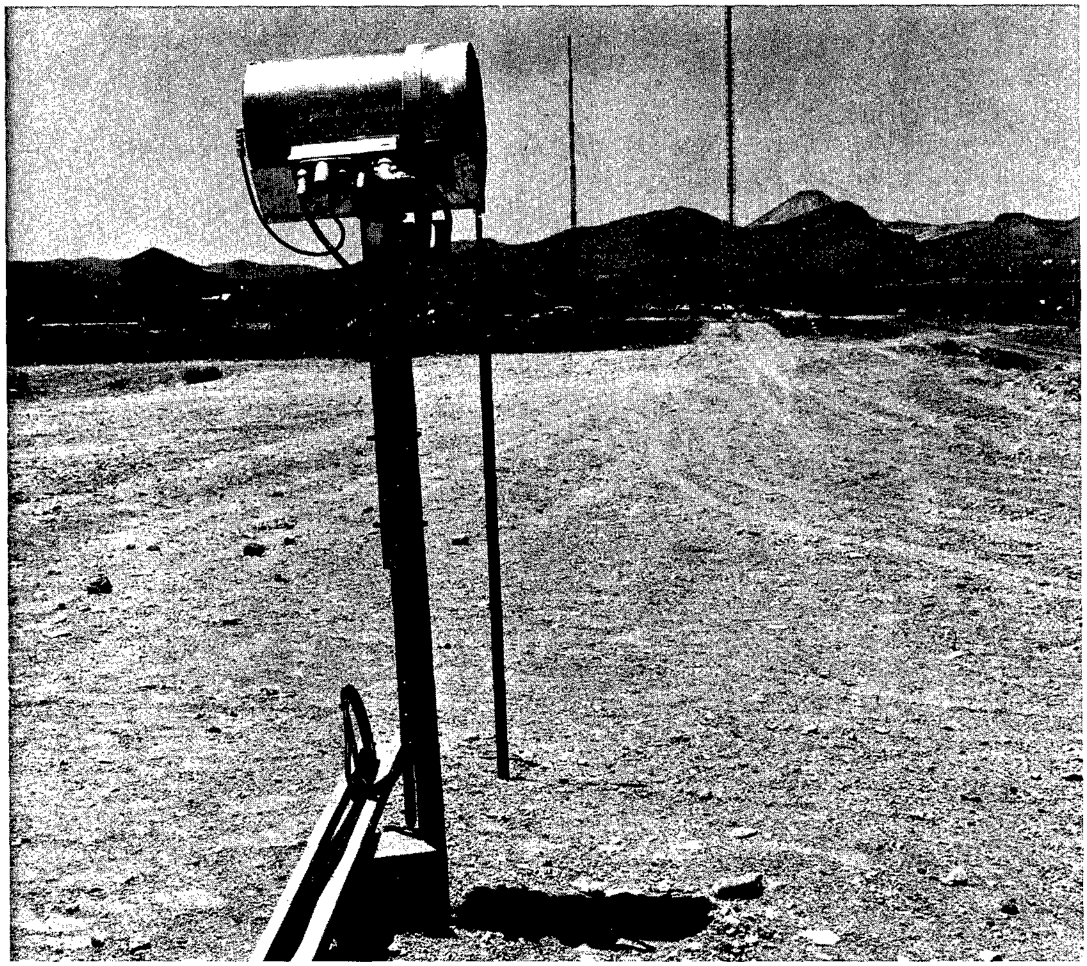

Fig. 2.4—Normalizing Channel No. 1—detector, mount, and preamplifier. BREN tower can be seen in background.

REFERENCE

1. P. W. Reinhardt and F. J. Davis, Improvements in the Threshold Detector Method of Fast Neutron Dosimetry, *Health Phys., 1:* 169-175 (1958).

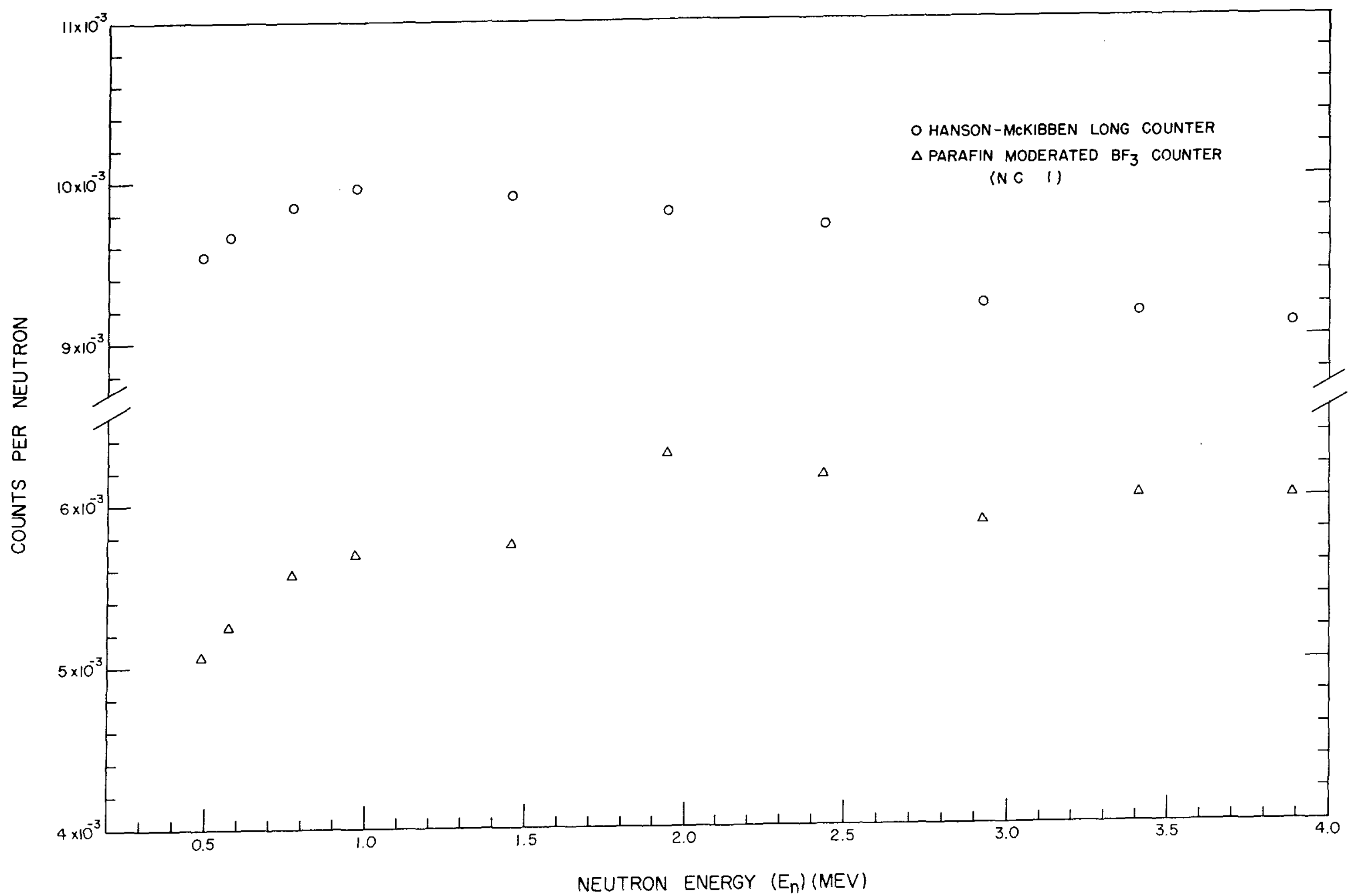

Fig. 2.5—Response of normalizing channel No. 1 as a function of neutron energy.

Chapter 3

NORMALIZATION TO STANDARD CONDITIONS

Radiation dose D as a function of distance R from a nuclear weapon detonated in an air-over-ground geometry can be fitted (for R > L) by the empirical equation[1,2]

$$D(R) = \frac{D_I e^{-R/L}}{R^2}$$

where L is the relaxation length and D_I is the apparent dose at unit distance obtained by an extrapolation of the equation to unit distance. In this equation a buildup term is included in the exponential term. However, for R < L, the equation does not yield appropriate values for the radiation field due to the initial buildup. The dose D_0, at unit distance from the detonation, is less than the value D_I obtained by extrapolation by a factor of about 2.

The relaxation length is a function of air density, ρ; hence the relationship

$$L = \frac{\rho_0}{\rho} L_0$$

is used to compute L for values of ρ other than some standard value ρ_0, i.e., to normalize data to a designated air density.

For the BREN reactor source, normalization to unit source yield was also necessary. Several power levels were used, and the reactor instrumentation did not yield sufficient differential and integral power-level information to meet the experimenters' needs. Therefore normalization of data, to a standard reactor power, was accomplished through the use of the normalizing channels and sulfur pellets and through the analysis of samples of fuel irradiated in the glory hole of the reactor core. By the use of the preceding methods, it was possible to arrive at a set of numbers which related the normalizing-channel response to reactor power as a function of reactor height. These numbers are important in a comparison of data which were taken at the same detector position and normalized to the normalizing channel but which were taken at different reactor heights. The normalizing-channel response (NC 2, total counts) as a function of reactor height, H_R, is shown in Fig. 3.1; A_s is the flux above the sulfur threshold at a distance of 28.5 in. from the core, and R is the slant range from reactor to detector.

Since the atmospheric conditions varied significantly during Operation BREN, corrections had to be made in the normalizing-channel readings for the different temperatures and pressures. The following typical analysis will acquaint the reader with the method used in making corrections in data taken over a range of temperatures and pressures.

The relaxation length in air for neutrons and gamma rays from the HPRR fission source was measured with the reactor at a height, H_R, of 1125 ft above the air–ground interface and with the detector at the interface. For neutrons, the relaxation length, L_{N_0}, was found to be 230 yards, and for gamma rays, L_{γ_0}, 311 yards. These two values were determined at a tem-

perature, $\overline{T_0}$, of 291.2°K and a pressure, P_0, of 25.32 in. Hg. Thus the standard conditions throughout this discussion are

$$L_{N_0} = 230 \text{ yards} = 690 \text{ ft}$$

$$\overline{T_0} = 291.2°\text{K} = 65°\text{F}$$

$$P_0 = 25.32 \text{ in. Hg}$$

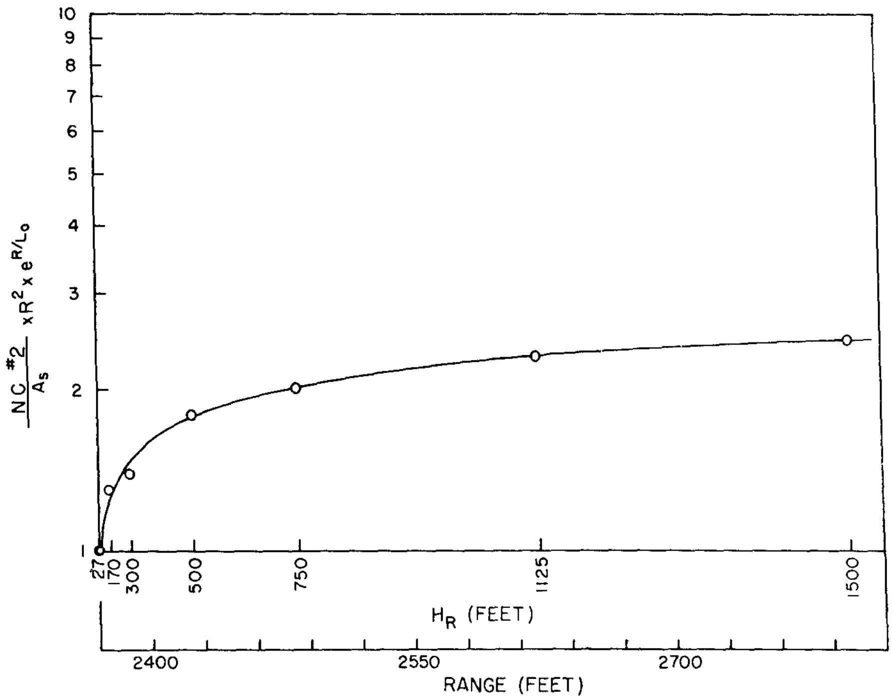

Fig. 3.1—Response of normalizing channel No. 2 at 790 yards as a function of reactor height.

Because the air density varies significantly between the reactor and the interface, the temperatures and pressures used are those at $H_R/2$. The pressure at $H_R/2$ had to be calculated with the use of available weather data from the Yucca Flat weather station. This calculation was performed by using the following formula:[3]

$$P_1 = P_2 \frac{A(1 + Bt) - H}{A(1 + Bt) + H}$$

where P_1 = pressure at $H_R/2$, in. Hg
P_2 = pressure at Yucca Flat station, in. Hg
$t = (T_1 + T_2)/2$, where T_1 = °C at $H_R/2$ and T_2 = °C at Yucca Flat
$B = 4 \times 10^{-3}$
$A = (1.6 \times 10^6)/30.48$
$H = 316 \text{ ft} + H_R/2$

The difference in elevation between the Yucca Flat weather station and the BREN experimental area is 316 ft.

The normalizing channels were corrected for pressure and temperature variations by use of the following formula:

$$D_1 = D \frac{e^{-R_L/L_{N_0}}}{e^{-R_L/L_{N_1}}} = De^{-R_L\left(\frac{1}{L_{N_0}} - \frac{1}{L_{N_1}}\right)}$$

where D = [total normalizing channel counts/integrated flux to sulfur pellet (A_s)]

R_L = slant distance between reactor and detector position

L_{N_0} = 230 yards

L_{N_1} = neutron relaxation length at $\overline{T_1}$ and P_1

$= L_{N_0}\,[(P_0/\overline{T_0})(\overline{T_1}/P_1)]$, where $\overline{T_0} = 291.2°K$ and $\overline{T_1} = (T_1 + 273)°K$

$\dfrac{e^{-R_L/L_{N_0}}}{e^{-R_L/L_{N_0}}}$ = correction factor for temperature and pressure

D_1 = temperature- and pressure-corrected normalizing-channel response, counts per unit flux above sulfur threshold at 28.5 in.

Table 3.1 gives values of D_1 vs. H_R for normalizing channel No. 1 at 1000 yards from the reactor tower and for normalizing channel No. 2 at 790 yards from the reactor tower (values of D_1 are given for a relaxation length of 230 yards and an air density of 1.02 g/liter).

Table 3.1—NORMALIZING-CHANNEL COUNTS PER UNIT SULFUR ACTIVATION AS A FUNCTION OF REACTOR HEIGHT

H_R, ft	Normalizing channel No. 1 at 1000 yards	Normalizing channel No. 2 at 790 yards
27	5.97×10^{-7}	4.03×10^{-5}
170	7.50×10^{-7}	5.07×10^{-5}
300	8.61×10^{-7}	5.41×10^{-5}
500	9.09×10^{-7}	5.92×10^{-5}
750	9.15×10^{-7}	5.95×10^{-5}
1125	8.44×10^{-7}	4.91×10^{-5}
1500	7.00×10^{-7}	3.80×10^{-5}

Use of the multiplier ($R_L^2 \times e^{R_L/L_{N_0}}$) transforms the normalizing-channel response to unit distance from the fission source. The values of D_1 given in Table 3.1 were corrected for inverse-square and air attenuation. These values are listed in Table 3.2 and are normalized to 27 ft reactor height.

Table 3.2 indicates that the response of the two normalizing channels to variations in reactor height agrees closely. Figure 3.1 graphically represents this behavior for the normalizing channel at 790 yards.

Table 3.2—NEUTRON-FLUX BUILDUP AT 790 AND 1000 YARDS AS A FUNCTION OF REACTOR HEIGHT

	Normalizing channel No. 1 at 1000 yards		Normalizing channel No. 2 at 790 yards	
H_R, ft	R_L, yards	$D_1 \times R_L^2 \times e^{R_L/L_{N_0}}$	R_L, yards	$D_1 \times R_L^2 \times e^{R_L/L_{N_0}}$
27	1000	1.00	790	1.00
170	1002	1.27	792	1.28
300	1005	1.49	796	1.40
500	1014	1.66	808	1.65
750	1031	1.86	828	1.92
1125	1068	2.16	874	2.15
1500	1118	2.44	934	2.46

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3. *Handbook of Chemistry and Physics*, 39th ed., Chemical Rubber Publishing Co., pp. 28-39, 1957-1958.

Chapter 4

OPERATIONAL AND NORMALIZATION DATA

Operational data and information necessary for normalization to standard conditions are presented in Tables 4.1 to 4.3. Fission-product analysis of samples irradiated in the core was used as the absolute calibration of power levels; the power levels listed are greater than the nominal values used in the field.

Table 4.1 — REACTOR OPERATION AND NORMALIZATION DATA

Steady-state Operation

Date	Run No.	Reactor power, watts	1/e to shutdown, sec	Normalizing channel (NC), counts/sec No. 1	Normalizing channel (NC), counts/sec No. 2	$\frac{NC\ 2}{NC\ 1}$	Flux to sulfur, neutrons/cm^2/sec	Micromicro-ammeter, amp
3/30/62	4A	0.3	600		0.88			0.77×10^{-9}
3/30/62	4B	72	600		241			1.70×10^{-7}
3/30/62	4C	72	600		229			1.68×10^{-7}
3/30/62	4D	72	600		242			1.68×10^{-7}
3/30/62	4E	72	600		244			1.71×10^{7}
4/1/62	5A	1.4	600	0.57	5.85	10.3		3.4×10^{-9}
4/1/62	5B	1.4	900	0.62	6.06	9.8		3.4×10^{-9}
4/1/62	5C	1.4	900	0.57	6.91	12.1		3.4×10^{-9}
4/1/62	5D	14.4	900	5.02	66.4	13.2		3.55×10^{-8}
4/1/62	5E	14.4	600	4.39	60.0	13.7		3.4×10^{-8}
4/1/62	5F	14.4	600	4.43	59.3	13.4		3.4×10^{-8}
4/1/62	5G	72	600	20.1	273	13.6		1.70×10^{-7}
4/3/62	6A	72	600	21.5	303	14.1		1.68×10^{-7}
4/3/62	6B	72	600	23.0	322	14.0		
4/3/62	6C	288	600	75.7	1066	14.1		6.75×10^{-7}
4/3/62	6D	288	600	76.6	1059	13.8		6.7×10^{-7}
4/3/62	6E	288	600	76.1	1048	13.8		6.8×10^{-7}
4/3/62	6F	1152	600	302	3994	13.2		2.72×10^{-6}
4/4/62	7A	14.4	660	3.09	41.8	13.5		3.4×10^{-8}
4/4/62	7B	72	600	17.3	242	14.0		1.70×10^{-7}
4/4/62	7C	288	600	73.4	1009	13.7		6.8×10^{-7}
4/4/62	7D	288	600	73.2	1019	13.9		6.8×10^{-7}
4/4/62	7E	1152	600	288	3967	13.8		2.72×10^{-6}
4/6/62	8A	288	600	72.4	1022	14.1		6.8×10^{-7}
4/6/62	8B	288	600	73.0	1026	14.0		6.8×10^{-7}
4/6/62	8C	288	600	74.3	1040	14.0		6.8×10^{-7}
4/6/62	8D	288	600	74.8	1045	14.0		6.8×10^{-7}
4/6/62	8E	288	600	74.7	1046	14.0		6.8×10^{-7}
4/7/62	9A		Scram					
4/7/62	9B	1440	600	355	4583	12.9		3.4×10^{-6}
4/7/62	9C	1440	600	362	4650	12.8		3.4×10^{-6}
4/7/62	9D	1440	600	550	6518	11.8		3.4×10^{-6}
4/9/62	10A	288	600	106	1445	13.6		6.8×10^{-7}
4/9/62	10B	288	600	109	1497	13.7		6.8×10^{-7}
4/9/62	10C	288	600	110	1497	13.6		6.8×10^{-7}
4/9/62	10D	288	600	104	1460	14.0		6.8×10^{-7}
4/9/62	10E	288	600	104	1410	13.6		6.8×10^{-7}
4/11/62	11A	72	600	25.7	362	14.1		1.7×10^{-7}
4/11/62	11B	288	600	108	1548	14.3		6.8×10^{-7}
4/11/62	11C	720	600	270	3640	13.5		1.7×10^{-6}
4/11/62	11D	720	600	275	3647	13.3		1.7×10^{-6}
4/11/62	11E	720	600	270	3550	13.1		1.7×10^{-6}
4/13/62	12A	1440	600	544	6675	12.3		3.4×10^{-6}
4/13/62	12B	1440	600	567	6693	11.8		3.4×10^{-6}
4/13/62	12C	1440	600	588	4516	16.2*		3.4×10^{-6}

*Wood arrangement on normalizing channel No. 2 rearranged.

(Table continues on following page.)

Table 4.1—REACTOR OPERATION AND NORMALIZING DATA (Continued)

Steady-state Operation

Date	Run No.	Reactor power, watts	1/e to shutdown, sec	Normalizing channel (NC), counts/sec No. 1	No. 2	NC 2 / NC 1	Flux to sulfur, neutrons/cm^2/sec	Micromicro-ammeter, amp
4/13/62	12D	1440	600	584	9092	15.6		3.4×10^{-6}
4/17/62	13A	1440	900	501	8321	16.6		3.3×10^{-6}
4/17/62	13B	1440	900	522	8579	16.4		3.3×10^{-6}
4/17/62	13C	1440	900	541	8879	16.4		3.3×10^{-6}
4/17/62	13D	1440	900	551	9138	16.6		3.3×10^{-6}
4/17/62	13E	1440	900	550	9280	16.9		3.3×10^{-6}
4/18/62	14A	72.2	600	27.0	441	16.3		1.7×10^{-7}
4/18/62	14B	72.2	600	28.8	478	16.6		1.7×10^{-7}
4/18/62	14C	1440	12598	587	9572	16.3		3.4×10^{-6}
4/23/62	15A	1440	15845	562	8983	16.0		3.45×10^{-6}
4/23/62	15B	288	599	113	1877	16.6		6.8×10^{-7}
4/23/62	15C	1440	6063	570	9243	16.2		3.45×10^{-6}
4/24/62	16A	1440	5344	541	8784	16.2		3.35×10^{-6}
4/26/62	17A	1440	10000* 9700†	549	8990	16.4		3.35×10^{-6}
4/27/62	17B	1440	14413	515	8522	16.5		3.35×10^{-6}
4/27/62	17C	1440	9487	485	8078	16.6		3.35×10^{-6}
4/30/62	18A	1440	10026	465	8268	17.8		3.35×10^{-6}
4/30/62	18B	1440	10568	494	8185	16.6		3.35×10^{-6}
5/1/62	19A	1440	10387	553	9143	16.5		3.35×10^{-6}
5/2/62	20A	1440	15071* 15307†	583	9465	16.2		3.35 10^{-6}
5/3/62	21A	1440	12185	602	9761	16.2	1.90×10^{12}	3.35×10^{-6}
5/4/62	22A	1440	13328	580	9700	16.7	1.91×10^{12}	3.4×10^{-6}
5/5/62	23A	1440	12305	561	9067	16.2		3.4×10^{-6}
5/9/62	24A	1440	13861	549	9349	17.0		3.4×10^{-6}
5/11/62	25A	1440	850	459	7793	17.0		3.4×10^{-6}
5/11/62	25B	1440	12007	582	9895	17.0		3.4×10^{-6}
5/17/62	28A	288	660	94.2			3.79×10^{7}	6.8×10^{-7}
5/18/62	29A	1440	10085	508	8730	17.2	1.92×10^{8}	3.3×10^{-6}

Burst Series

Date	Run No.	Fission yield	Neutrons/cm^2
5/21/62	B30A 1	No burst	
5/21/62	B30B 2	No burst	
5/21/62	B30C 3	No burst	
5/22/62	B31A 4	No burst	
5/22/62	B31B 5	2.4×10^{16}	
5/23/62	B32A 6	3.0×10^{16}	
5/24/62	B33B 7	3.4×10^{16}	1.60×10^{11}
5/25/62	B34A 8	3.3×10^{16}	1.28×10^{11}
5/26/62	B35B 9	5.1×10^{16}	1.88×10^{11}
5/26/62	B35C 10	4.2×10^{16}	1.45×10^{11}
5/28/62	B36A 11	4.5×10^{16}	1.27×10^{11}

*Normalizing channel No. 1.
†Normalizing channel No. 2.

(Table continues on following page.)

Table 4.1—REACTOR OPERATION AND NORMALIZING DATA (Continued)

Steady-state Operation

Date	Run No.	Reactor power, watts	1/e to shutdown, sec	Normalizing channel (NC), counts/sec No. 1	No. 2	NC 2 / NC 1	Flux to sulfur, neutrons/cm^2/sec	Micromicro-ammeter, amp
5/30/62	37A	1440	13868	532	9446	17.8	1.77×10^8	3.35×10^{-6}
6/1/62	38A	1440	1660	565	9733	17.2	1.99×10^8	3.35×10^{-6}
6/2/62	39A	1440	18972	578	9890	17.1	1.76×10^8	3.35×10^{-6}
6/4/62	40A	1440	12604	428			1.71×10^8	3.35×10^{-6}
6/5/62	40B	1440	12364	425			1.88×10^8	3.35×10^{-6}
6/5/62	41A	1440	10024	660	9899	15.0	1.94×10^8	3.35×10^{-6}
6/5/62	41B	1440	13806	684	10420	15.2	1.98×10^8	3.35×10^{-6}
6/7/62	42A	1440	17108	608	9170	15.1	2.03×10^8	3.35×10^{-6}
6/8/62	43A	1440	13622	626	10670	17.0	2.02×10^8	3.35×10^{-6}
6/11/62	44A	1440	14702	603	10100	16.7	1.99×10^8	3.35×10^{-6}
6/11/62	44B	1440	14820	643			2.08×10^8	3.35×10^{-6}
6/12/62	45A	1440	900	612	10600	17.3	1.91×10^8	3.35×10^{-6}
6/13/62	45B	1440	1205	589	10340	17.6	1.84×10^8	3.35×10^{-6}
6/14/62	46A	1440	4382	393	7088	18.0	1.97×10^8	3.35×10^{-6}
6/14/62	46B	1440	6423	518	8950	17.3	1.97×10^8	3.35×10^{-6}
6/14/62	46C	1440	3782	555	9543	17.2	1.93×10^8	3.35×10^{-6}
6/18/62	47A	1440	9001	159*	8464	53.2*	1.98×10^8	3.35×10^{-6}
6/19/62	48A	1440	10383	168	8810	52.4	1.95×10^8	3.35×10^{-6}
6/20/62	49A	1440	18789	188	10420	55.4	2.00×10^8	3.35×10^{-6}
6/20/62	49B	1440	14518	199	13397	67.3	1.97×10^8	
6/21/62	49E	1440	7863	181	11589	64.0	1.85×10^8	2.8×10^{-6}
6/22/62	50A	1440	13023	159	8420	53.0	1.89×10^8	3.35×10^{-6}
6/23/62	51A	1440	8642	113	7520	66.5	1.81×10^8	3.35×10^{-6}
6/23/62	51B	1440	6602	183	11300	61.7	1.97×10^8	3.35×10^{-6}
6/26/62	52A	1440	7655	121	8180	67.6	1.96×10^8	3.35×10^{-6}
6/26/62	52B	1440	2401	132	8583	65.0	1.85×10^8	3.35×10^{-6}
6/26/62	52C	1440	7206	194	12650	65.2	2.03×10^8	3.35×10^{-6}
6/27/62	53B	1440	1141	164	10750	65.5	1.83×10^8	3.35×10^{-6}
6/27/62	53C	288	452					6.4×10^{-7}
6/27/62	53C	1440	4502	161	10700	66.4	1.80×10^8	3.35×10^{-6}
6/27/62	53D	1440	1250	201	12780	63.6	1.93×10^8	3.35×10^{-6}

*Normalizing channel No. 1 moved to 1000 yards.

Table 4.2 —METEOROLOGICAL AND ELEVATION DATA FOR REACTOR OPERATION

			Yucca Station		BREN area		
Date	Run No.	Hour	Surface temperature at 3924 ft mean sea level, °F	Barometric pressure, in. Hg	Temperature at 4240 ft mean sea level + $H_R/2$, °F	Relative humidity, %	Reactor height, ft
			Steady-state Operation				
3/30/62	4A	0800	48	26.095	50	28	27
3/30/62	4B	1200	60	26.090	50	19	27
3/30/62	4C	1300	61	26.070	50	14	27
3/30/62	4D	1600	64	26.050	55	13	27
3/30/62	4E	1700	63	26.055	55	17	27
4/1/62	5A	0930	58	26.087	55	21	27
4/1/62	5B	1030	65	26.060	55	14	27
4/1/62	5C	1130	68	26.037	60	12	27
4/1/62	5D	1400	71	25.970	60	12	27
4/1/62	5E	1500	70	25.950	60	10	27
4/1/62	5F	1600	59	25.940	60	13	27
4/1/62	5G	1700	67	25.940	60	12	27
4/3/62	6A	1000	61	26.030	55	17	27
4/3/62	6B	1100	68	26.020	58	18	27
4/3/62	6C	1200	70	26.005	60	17	27
4/3/62	6D	1400	71	25.960	60	13	27
4/3/62	6E	1530	69	25.950	60	15	27
4/3/62	6F	1700	68	25.955	60	21	27
4/4/62	7A	0920	59	26.118	55	36	27
4/4/62	7B	1030	70	26.127	60	22	27
4/4/62	7C	1500	73	26.060	65	13	27
4/4/62	7D	1630	75	26.060	65	13	27
4/4/62	7E	1730	74	26.060	65	12	27
4/6/62	8A	1400	73	26.280	60	12	27
4/6/62	8B	1500	73	26.250	62	12	27
4/6/62	8C	1600	75	26.240	62	12	27
4/6/62	8D	1700	73	26.230	65	12	27
4/6/62	8E	1800	70	26.220	65	15	27
4/7/62	9B	1000	75	26.105	60	13	27
4/7/62	9C	1100	77	26.065	60	14	27
4/7/62	9D	1400	81	26.000	65	9	300
4/9/62	10A	1530	72	25.818	60	17	300
4/9/62	10B	1630	72	25.813	62	18	300
4/9/62	10C	1800	70	25.805	60	18	300
4/9/62	10D	2030	65	25.800	60	21	300
4/9/62	10E	2130	66	25.805	58	22	300
4/11/62	11A	1200	72	26.155	58	42	300
4/11/62	11B	1500	75	26.110	62	10	300
4/11/62	11C	1630	77	26.105	62	11	300
4/11/62	11D	1800	74	26.100	62	13	300
4/11/62	11E	2000	70	26.145	60	13	300
4/13/62	12A	1200	80	26.100	60	15	300
4/13/62	12B	1400	84	26.065	70	10	300
4/13/62	12C	1700	83	26.040	70	10	300
4/13/62	12D	1800	81	26.040	70	10	300

(Table continues on following page.)

Table 4.2 — METEOROLOGICAL AND ELEVATION DATA FOR REACTOR OPERATION (Continued)

			Yucca Station		BREN area		
Date	Run No.	Hour	Surface temperature at 3924 ft mean sea level, °F	Barometric pressure, in. Hg	Temperature at 4240 ft mean sea level + $H_R/2$, °F	Relative humidity, %	Reactor height, ft
			Steady-state Operation				
4/17/62	13A	1030	78	26.138	65	12	1125
4/17/62	13B	1200	82	26.120	68	12	1125
4/17/62	13C	1400	87	26.090	70	8	1125
4/17/62	13D	1500	85	26.085	70	9	1125
4/17/62	13E	1600	84	26.080	70	8	1125
4/18/62	14A	1000	77	26.17	65	13	300
4/18/62	14B	1330	83	26.11	70	16	300
4/18/62	14C	1500	86	26.07	75	16	1125
4/23/62	15A	1100	73	26.155	65	17	1125
		1200	79	26.135	65	17	
		1300	80	26.110	65	15	
		1400	81	26.080	65	15	
		1500	81	26.050	65	15	
4/23/62	15B	1600	82	26.040	65	16	1125
4/23/62	15C	1800	75	26.030	65	15	1125
		1900	69	26.030	65	20	
		2000	60	26.050	55	26	
4/24/62	16A	1030	79	26.032	65	16	1125
		1100	79	26.025	65	16	
		1200	81	26.010	65	17	
4/26/62	17A	1800	70	25.91	60	16	1125
		1900	65	25.93	58	19	
		2000	64	25.95	58	20	
		2100	57	25.97	55	21	
4/26/62	17B	2300	50	25.98	55	27	1125
		0000	47	25.98	55	31	
		0100	45	25.97	55	31	
		0200	43	25.97	55	38	
		0300	42	25.98	55	33	
4/27/62	17C	0430	43	25.98	55	34	1125
		0500	44	25.98	53	35	
		0600	48	25.99	50	30	
		0700	51	25.99	50	33	
4/30/62	18A	1100	61	26.185	50	13	1125
		1200	65	26.170	50	11	
		1300	65	26.165	52	11	
		1400	64	26.145	55	11	
4/30/62	18B	1600	67	26.110	55	9	1125
		1700	67	26.110	55	8	
		1800	65	26.110	55	10	
		1900	55	26.125	55	14	

(Table continues on following page.)

Table 4.2 —METEOROLOGICAL AND ELEVATION DATA FOR REACTOR OPERATION (Continued)

			Yucca Station		BREN area		
Date	Run No.	Hour	Surface temperature at 3924 ft mean sea level, °F	Barometric pressure, in. Hg	Temperature at 4240 ft mean sea level + $H_R/2$, °F	Relative humidity, %	Reactor height, ft
			Steady-state Operation				
5/1/62	19A	2030	57	26.100	65	14	1125
		2100	50	26.100	65	18	
		2200	48	26.105	60	20	
		2300	45	26.105	55	20	
		2330	45	26.105	55	21	
5/2/62	20A	1630	81	25.965	70	8	1125
		1700	80	25.960	70	8	
		1800	78	25.950	68	8	
		1900	70	25.960		11	
		2000	63	25.975		15	
		2030	59	25.980		15	
5/3/62	21A	1500	86	25.920	75	7	1125
		1600	84	25.910	75	9	
		1700	83	25.900	75	9	
		1800	80	25.910	70	9	
		1830	78	25.915	70	10	
5/4/62	22A	1500	88	25.97	72	10	1125
		1600	86	25.97	75	10	
		1700	81	25.97		11	
		1800	80	25.97		13	
		1830	78	25.98		14	
5/5/62	23A	1200	85	26.11	70	13	1125
		1300	87	26.10	70	11	
		1400	86	26.09	75	10	
		1500	86	26.07	75	10	
5/9/62	24A	0700	65	25.98	58	18	1125
		0800	71	25.97		11	
		0900	75	25.98		9	
		1000	77	25.97		8	
		1100	81	25.97	70	6	
5/11/62	25A	1800	70	25.805	62	6	1125
5/11/62	25B	1830	68	25.800	60	8	1125
		1900	67	25.800	58	9	
		2000	63	25.790	55	9	
		2100	58	25.785	55	12	
		2200	51	25.780	50	15	
5/14/62	26						
5/16/62	27						
5/17/62	28A	1230					300
5/18/62	29A	1130	72	26.017	60	19	1125
		1200	72	26.010	60	19	
		1300	76	25.990	60	14	
		1400	76	25.970	60	13	

(Table continues on following page.)

Table 4.2—METEOROLOGICAL AND ELEVATION DATA FOR REACTOR OPERATION (Continued)

			Yucca Station		BREN area		
Date	Run No.	Hour	Surface temperature at 3924 ft mean sea level, °F	Barometric pressure, in. Hg	Temperature at 4240 ft mean sea level + $H_R/2$, °F	Relative humidity, %	Reactor height, ft
			Burst Series				
5/21/62	B30A 1	1355	68	25.97	55	13	96
5/21/62	B30B 2	1704	68	25.98	57	26	106
5/21/62	B30C 3	1851	61	26.01	57	29	98
5/22/62	B31A 4	1056	68	26.05	55	21	101
5/22/62	B31B 5	1247	72	26.03	60	19	97
5/23/62	B32A 6	1040	74	25.82	60	18	107
5/24/62	B33A 7						
5/24/62	B33B 7	1320	70	25.83	57	14	1125
5/25/62	B34A 8	1352	68	25.84	58	17	1125
5/26/62	B35A 9						
5/26/62	B35B 9	1101	62	25.81	50	27	1125
5/26/62	B35C 10	1526	64	25.74	56	18	1125
5/28/62	B36A 11	1158	72	25.90	55	26	1125
			Steady-state Operation				
5/30/62	37A	1000	79	25.98	60	19	1125
		1100	80	25.96	62	15	
		1200	82	25.93	65	11	
		1300	84	25.92	68	12	
		1400	83	25.91	70	13	
6/1/62	38A	1230	87	26.04	63	14	1125
		1300	86	26.04	63	17	
6/2/62	39A	1000	85	26.04	70	15	1125
		1100	86	26.02	70	13	
		1200	88	25.99	72	11	
		1300	90	25.95	72	12	
		1400	91	25.92	75	9	
		1500	90	25.90	78	7	
6/4/62	40A	1530	79	25.86	65	10	1500
		1600	79	25.86	65	10	
		1700	77	25.86	65	10	
		1800	75	25.86	65	12	
		1900	72	25.86	65	14	
6/4/62	40B	2130	62	25.88	65	20	1500
6/4/62		2200	57	25.89	60	24	
6/4/62		2300	53	25.90	55	22	
6/5/62		0000	50	25.91	55	22	
6/5/62		0100	47	25.91	55	26	
6/5/62	41A	1400	81	25.95	66	9	500
		1500	82	25.94	68	9	
		1600	81	25.93	70	7	
		1700	79	25.92	68	9	
6/5/62	41B	1900	72	25.94	70	9	500
		2000	72	25.95	70	11	
		2100	64	25.97	65	13	
		2200	58	25.98	60	15	
		2300	53	25.99	55	17	

(Table continues on following page.)

Table 4.2 — METEOROLOGICAL AND ELEVATION DATA FOR REACTOR OPERATION (Continued)

Date	Run No.	Hour	Yucca Station: Surface temperature at 3924 ft mean sea level, °F	Yucca Station: Barometric pressure, in. Hg	BREN area: Temperature at 4240 ft mean sea level + $H_R/2$, °F	BREN area: Relative humidity, %	BREN area: Reactor height, ft
			Steady-state Operation				
6/7/62	42A	1430	80	25.98	67	8	1125
		1500	80	25.97	67	8	
		1600	80	25.96	67	8	
		1700	79	25.95	68	7	
		1800	78	25.96	69	6	
		1900	72	25.97	70	6	
6/8/62	43A	1600	85	25.93	70	9	1125
		1700	85	25.91	75	7	
		1800	84	25.91	75	8	
		1900	77	25.92	75	11	
		2000	74	25.92	75	11	
6/11/62	44A	1100	88	26.03	72	5	1125
		1200	87	26.02	72	9	
		1300	87	26.00	75	9	
		1400	90	25.98	75	7	
		1500	89	25.96	77	6	
6/11/62	44B	1730	86	25.94	78	7	1125
		1800	85	25.94	78	7	
		1900	81	25.93	78	6	
		2000	78	25.94	74	6	
		2100	67	25.94	72	8	
		2130	64	25.95	70	9	
6/12/62	45A	2330	74	25.82	70	14	300
6/13/62	45B	0200	70	25.80	65	17	300
6/14/62	46A	1200	62	25.73	55	10	1500
		1300	64	25.72	55	28	
6/14/62	46B	1500	68	25.69	55	19	1125
		1600	66	25.69	55	20	
		1700	63	25.69	55	23	
6/14/62	46C	1900	59	25.71	55	32	500
		2000	55	25.72	55	47	
6/18/62	47A	1600	93	26.07	80	9	1500
		1700	92	26.06	80	7	
		1800	91	26.06	79	8	
		1900	86	26.07	79	10	
6/19/62	48A	1500	97	26.05	81	6	1500
		1600	97	26.04	81	6	
		1700	96	26.02	82	6	
		1730	95	26.02	82	6	
6/20/62	49A	0930	88	26.07	75	12	1125
		1000	88	26.07	76	12	
		1100	93	26.05	77	9	
		1200	93	26.04	78	7	
		1300	95	26.02	79	6	
		1400	95	26.00	79	7	
		1430	96	25.99	80	6	

(Table continues on following page.)

Table 4.2 — METEOROLOGICAL AND ELEVATION DATA FOR REACTOR OPERATION (Continued)

Date	Run No.	Hour	Yucca Station: Surface temperature at 3924 ft mean sea level, °F	Yucca Station: Barometric pressure, in. Hg	BREN area: Temperature at 4240 ft mean sea level + $H_R/2$, °F	BREN area: Relative humidity, %	BREN area: Reactor height, ft
			Steady-state Operation				
6/20/62	49B	1800	94	25.96	84	6	500
		1900	89	25.97	84	8	
		2000	81	25.97	82	12	
		2100	74	25.97	80	13	
		2200	69	25.98	79	20	
6/20/62	49C	Scram					
6/20/62	49D	Scram					
6/20/62	49E	2300	66	25.99	78	19	500
6/21/62		0000	61	25.98	78	19	
		0100	63	25.98	78	23	
6/22/62	50A	1300	92	25.88	79	12	
		1400	91	25.86	79	9	
		1500	93	25.85	79	10	
		1600	93	25.84	80	11	
		1630	92	25.83	80	10	
6/23/62	51A	1030	87	25.97	73	6	27
		1100	88	25.97	74	4	
		1200	90	25.97	75	5	
		1300	92	25.97	76	4	
6/23/62	51B	1500	92	25.95	80	4	300
		1600	92	25.94	80	4	
		1700	91	25.94	80	5	
6/26/62	52A	1000	92	25.91	83		27
		1100	95	25.90	86		
		1200	95	25.89	86		
6/26/62	52B	1600	97	25.82	86		
		1700	95	25.82	86		
6/26/62	52C	1830	92	25.80	86		300
		1900	89	25.80	86		
		2000	83	25.80	85		
		2030	82	25.80	84		
6/27/62	53B	1730	92	25.88	84		170
		1800	92	25.88	84		
6/27/62	53C	1930	87	25.88	84		170
		2000	86	25.88	82		
		2100	84	25.88	82		
6/27/62	53D	2230	67	25.89	81		750

Table 4.3—OPERATIONAL DATA FOR Co^{60} PHASE OF OPERATION BREN

Date	Run No.	Duration, min	Source height, ft	Hour	BREN temperature, °F	Yucca Flat Temperature, °F	Yucca Flat Barometric pressure, in. Hg	Yucca Flat Relative humidity, %
7/4/62	γ1A	141	27	1630	84	95	25.90	
				1700	84	94	25.90	
				1800	84	90	25.90	
				1845	83	83	25.95	
7/4/62	γ1B	123	300	2100	83	77	25.95	
				2200	78	67	25.95	
				2300		63	25.95	
7/5/62	γ2A	422	1500	1000	78	93	25.92	
				1100	79	94	25.91	
				1200	80	95	25.90	
				1300	81	97	25.89	
				1400	81	98	25.85	
				1500	81	96	25.84	
				1600	81	95	25.82	
				1700	81	93	25.81	
7/5/62	γ2B	145	1125	1900	83	81	25.81	
				2000	81	76	25.83	
				2100	80	77	25.84	
7/9/62	γ3A	92	27	1300	80	95	25.94	
				1400	80	95	25.93	
				1500	81	94	25.92	
7/9/62	γ3B	222	1125	1900	81	86	25.91	
				2000	80	82	25.93	
				2100	78	83	25.94	
				2200	76	81	25.94	
				2300	76	77	25.95	
7/10/62	γ4A	290	1125	1300	80	93	26.00	
				1400	80	94	25.99	
				1500	81	94	25.98	
				1600	81	94	25.97	
				1700	82	93	25.96	
7/10/62	γ4B	177	1125	1930	83	79	25.98	
				2000	80	75	25.98	
				2100	79	65	25.99	
				2200	78	62	26.00	
7/11/62	γ5A	311	1125	1000	75	88	26.03	
				1100	76	91	26.00	
				1200	78	92	25.98	
				1300	79	94	25.97	
				1400	79	95	25.95	
				1500	80	94	25.94	
				1530	80	94	25.93	
7/12/62	γ6A	400	1125	1130	70	82	25.88	
				1200	69	82	25.88	
				1300	69	82	25.86	
				1400	70	82	25.85	
				1500	70	81	25.84	
				1600	70	78	25.83	
				1700	68	63	25.85	

(Table continues on following page.)

Table 4.3—OPERATIONAL DATA FOR Co^{60} PHASE OF OPERATION BREN (Continued)

Date	Run No.	Duration, min	Source height, ft	Hour	BREN temperature, °F	Yucca Flat Temperature, °F	Yucca Flat Barometric pressure, in. Hg	Yucca Flat Relative humidity, %
7/13/62	γ7A	173	1125	1340	68	86	25.88	
				1400	69	86	25.88	
				1500	70	86	25.87	
				1600	71	89	25.85	
				1630	72	88	25.84	
7/14/62	γ8A	254	1125	1430	76	91	25.90	
				1500	75	91	25.90	
				1600	76	90	25.88	
				1700	75	89	25.88	
				1800	76	88	25.88	
				1830	76	83	25.88	
7/16/62	γ9A	245	1125	0900	70	83	26.04	17
				1000	71	87	26.04	15
				1100	73	90	26.03	13
				1200	74	88	26.02	11
				1300	75	89	26.00	14
7/16/62	γ9B	120	300	1600	80	92	25.95	15
				1700	79	91	25.95	16
				1800	79	86	25.96	17
7/16/62	γ9C	240	1125	1930	82	78	25.97	24
				2000	78	75	25.97	26
				2100	78	70	25.99	38
				2200	77	68	25.99	23
				2300	74	68	25.99	23
				2330	74	63	26.00	21
7/17/62	γ10A	42	27	1030	78	89	26.03	12
				1100	77	90	26.03	10
7/17/62	γ10B	78	27	1130	77	92	26.02	9
				1200	78	93	26.01	7
				1300	78	92	26.01	8
7/17/62	γ10C	120	300	1400	81	93	25.99	8
				1500	81	93	25.98	5
				1600	80	92	25.97	7
7/18/62	γ11A	516	1125	0900	74	85	26.05	6
				1100	76	89	26.04	4
				1200	77	88	26.04	4
				1300	78	93	26.03	5
				1400	79	92	26.02	3
				1500	80	91	26.00	5
				1600	80	92	25.99	5
				1700	80	90	25.98	5
				1800	80	88	25.97	5
7/19/62	γ12A	60	27	1030	78	89	26.12	8
				1100	78	90	26.12	9
				1130	78	90	26.12	8
7/19/62	γ12B	75	300	1400	82	91	26.09	8
				1500	80	93	26.08	8

(Table continues on following page.)

Table 4.3 —OPERATIONAL DATA FOR Co^{60} PHASE OF OPERATION BREN (Continued)

Date	Run No.	Duration, min	Source height, ft	Hour	BREN temperature, °F	Yucca Flat Temperature, °F	Yucca Flat Barometric pressure, in. Hg	Yucca Flat Relative humidity, %
7/19/62	γ12C	68	1125	1600	83	93	26.07	5
				1700	82	91	26.06	6
7/20/62	γ13A	43	27	1000	82	88	26.18	8
				1045	80	92	26.18	10
7/20/62	γ13B	36	300	1130	83	92	26.17	11
				1200	82	93	26.17	11
7/21/62	γ14A	99	300	0830	80	86	26.18	16
				0900	75	88	26.18	14
				1000	76	92	26.17	15
7/21/62	γ14B	128	300	1130	82	94	26.14	16
				1200	82	95	26.14	15
				1300	82	93	26.13	15
				1330	82	92	26.13	15
7/21/62	γ14C	119	300	1530	84	89	26.12	18
				1600	83	88	26.11	21
				1700	81	86	26.09	23
				1730	80	84	26.10	25
7/23/62	γ15A	71	300	0830	71	80	26.10	45
				0900	71	81	26.09	37
				0930	71	82	26.08	34
7/23/62	γ15B	36	100	1000	74	83	26.08	32
7/23/62	γ15C	66	27	1145	78	88	26.05	25
				1200	78	89	26.04	24
				1300	78	89	26.02	22
7/23/62	γ15D	15	27	1330	82	91	26.01	20

Chapter 5

AIR-DOSE CURVES AND HPRR NEUTRON-LEAKAGE DATA

Typical air-dose curves are presented in Figs. 5.1 and 5.2. The information presented in these figures was obtained with Radsan[1] and Phil[2] dosimeters, and it was normalized by the methods in Chap. 3 and the data in Chap. 4. For an air density of 1.02 g/liter, the relaxation lengths for fast neutrons and gamma radiation from the HPRR at an elevation of 1125 ft were 230 and 311 yards, respectively. These reduce to 181 and 245 yards, respectively, at an air density of 1.293 g/liter. For the Co^{60} source at a height of 300 ft above the ground, the relaxation length was 231 yards for an air density of 1.01 g/liter, or 180 yards at 1.293 g/liter. The leakage neutron spectrum from the HPRR, measured with threshold detectors[3] located 44 in. from the center of the core, is shown in Fig. 5.3. More detailed information on air-dose distributions is included in Report CEX-62.14,[4] and energy and angular distribution data are given in Reports CEX-62.12[5] and CEX-62.13.[6]

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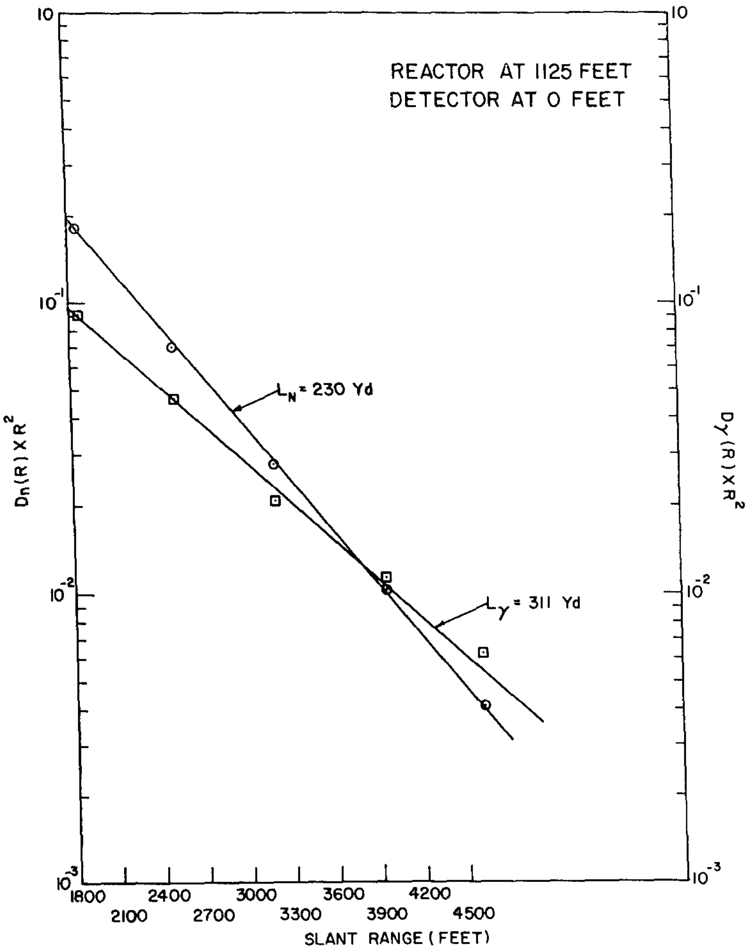

Fig. 5.1 —Neutron- and gamma-radiation air-dose curves for a reactor height of 1125 ft. Air density is 1.02 g/liter.

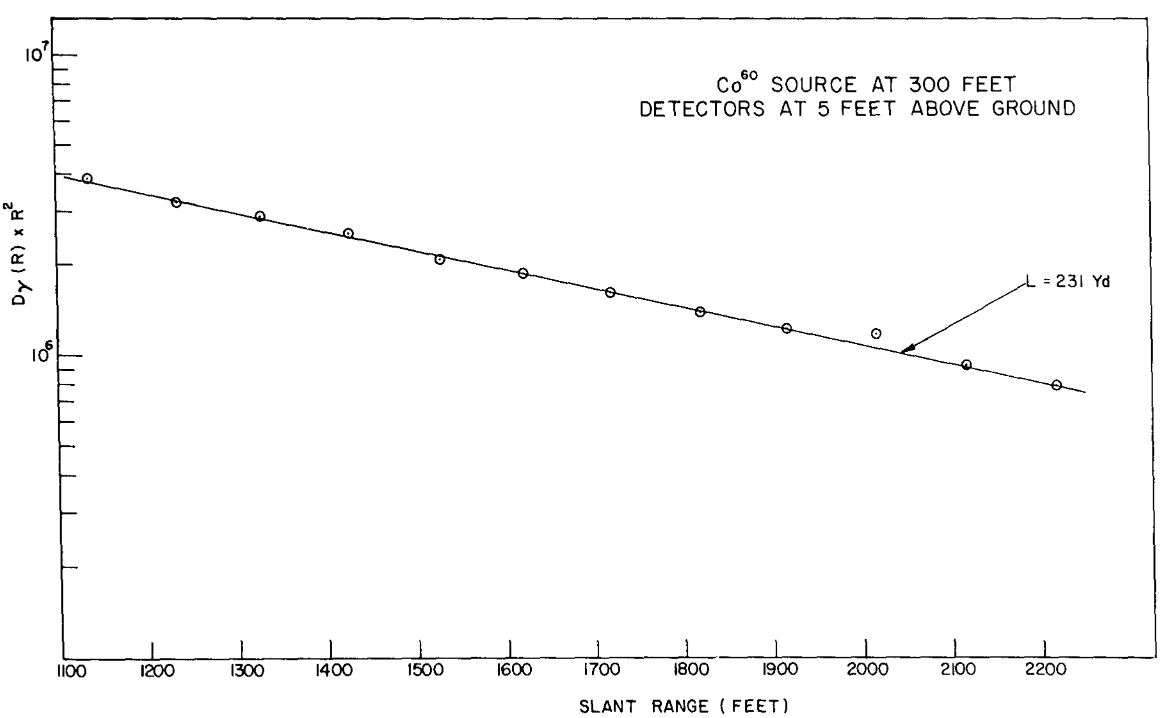

Fig. 5.2 —Gamma-radiation air-dose curve for Co^{60} source at a height of 300 ft.

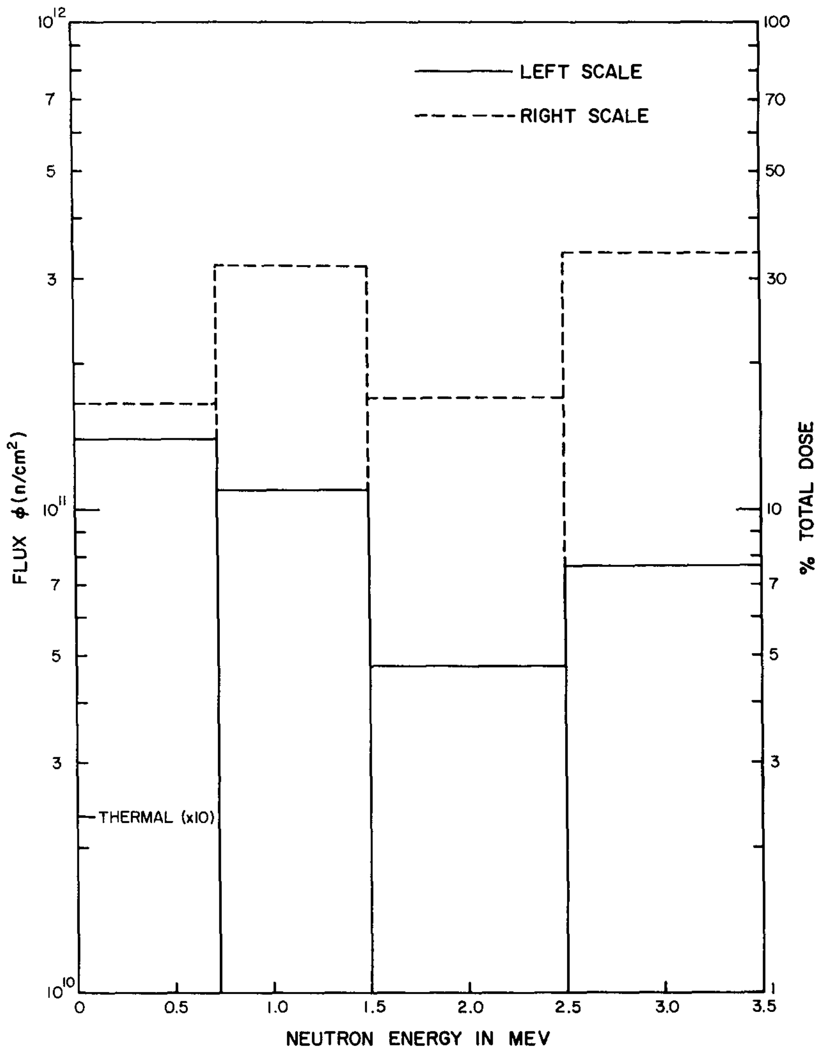

Fig. 5.3 — Neutron dose and flux histogram.

Chapter 6

SUMMARY

This report describes the physical facilities used during Operation BREN with both the ORNL HPRR and a 1.2-kilocurie Co^{60} gamma source. Tabular data are given with appropriate formulas so that corrections can be made in the data to compensate for the significant changes in air density during Operation BREN.

As the reactor was raised from 27 ft to 1500 ft, an apparent increase in neutron flux was measured at 790 and 1000 yards from the tower; the increase was approximately 2.5. This factor is given in Table 3.2 and is illustrated in Fig. 3.1.

The relaxation lengths for neutrons and gamma rays in air, for a point fission source at 1125 ft above the ground, are 181 and 245 yards, respectively, when data are reduced to an air density of 1.293 g/liter. The relaxation length for gamma rays in air from a Co^{60} point source exposed at 300 ft is 180 yards at 1.293 g/liter.

The energy spectrum for HPRR leakage neutrons was measured at a distance of 44 in. from the core by utilizing threshold detectors. A histogram of the spectrum is given in Fig. 5.3.